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PREPLANNED PRODUCT IMPROVEMENT AND OTHER MODIFICATION STRATEGIES: LESSONS FROM PAST AIRCRAFT MODIFICATION PROGRAMS

Frederick Biery, Mark Lorell

December 1981

N-1794-AF

Prepared For The United States Air Force

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Pre-Planned Product Improvement (P3I) is a weapon system acquisition strategy formulated in the late 1970's in response to the high development costs of new systems, lengthening acquisition intervals, increasing age of current inventories, constrained budgets, and various technology trends. It is founded on the assumption that quality enhancement modification of existing inventory systems is a cheaper and quicker way to modernize than the development of entirely new systems. The P3I strategy is aimed at facilitating this process; its central element is the design of new systems from their origins to accommodate future quality upgrades. Discussion of the merits and disadvantages of P3I, however, remains abstract and theoretical. This Note reviews the circumstances that led to the formulation of P3I, clarifies the implications of the concept and offers an initial assessment of the policy as applied to aircraft systems based on a careful and extensive examination of past major aircraft modification efforts. The authors conclude that long-range pre-planning during the design stage is impractical. This Note also provides lessons drawn from past experience on the conduct of modification programs in general.

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PREFACE

This Note reports research conducted as part of the project entitled "Air Force Acquisition Options for the 1980s," under the auspices of the Resource Management Program of Project AIR FORCE. It offers an initial assessment of Preplanned Product Improvement (P^3I) as an alternative strategy for aircraft acquisition and evaluates various elements of past modification programs. It should be of interest to Air Force, government, and business officials concerned with improving the military aircraft acquisition and modification process.

SUMMARY

Toward the end of the 1970s various defense and aerospace industry spokesmen expressed increasing interest in preplanning the modification of inventory weapon systems as a coherent force modernization strategy. The term Preplanned Product Improvement (P^3I) was coined to differentiate this strategy from past ad hoc modification efforts. Many advocates of P^3I viewed it as a necessary alternative to the development and acquisition of entirely new systems, in response to the high costs of R&D programs, lengthening acquisition intervals, increasing age of the current inventory, constrained budgets, and various technology trends. Discussion of the merits and disadvantages of P^3I, however, remained abstract and theoretical.

The objective of the research described here is to clarify the P^3I concept, present an initial broad assessment of it as a force modernization strategy, and offer some observations on the conduct of modification programs in general. Our research emphasized application of the policy to aircraft systems. The central element of the concept is the design of a system from its origins to accommodate future quality upgrades. Thus, P^3I assumes that a designer can anticipate needed improvements or possible changes in requirements well in the future with enough specificity to allow the initial version of the aircraft to be designed to accommodate these improvements, or that the designer can develop a specific set of new design rules beyond currently accepted good design practices that would imbue air vehicles with a much higher degree of inherent modification flexibility than is currently the norm.

To arrive at an initial assessment of the P^3I strategy, we adopted a case study approach. First we examined the modification histories of those few aircraft where some preplanning could be clearly discerned in the initial design phase. Aircraft that have enjoyed particularly long inventory lives and that have often been successfully modified were then studied to determine whether any common design approach had facilitated the modification process. In addition, we attempted to assess what more the original designers could have done to anticipate and accommodate future modifications. Sources of information on past aircraft modification programs included original program documents, discussions with appropriate aerospace industry personnel when possible, and published and private accounts of the modification programs.

Past modification programs with elements similar to P^3I were aimed only at specific subsystem upgrades over a fairly short time horizon. Some observers criticized these programs at the time. The original configurations were alleged to be below optimal performance capabilities because of the inclusion of "growth" provisions, and the additional investment in the initial design phase was thought wasted if the anticipated modifications were not funded or if requirements changed. An examination of often-modified air vehicles with long inventory lives revealed that in almost all cases no special provision (beyond good design practices) for future modifications was made in the initial design phase, there is no special common design approach that facilitated the modification process, and it is extremely unlikely the original designers could have anticipated the changes in requirements and the types of modifications eventually carried out.

These results led to the conclusion that preplanning far into the future is probably unworkable. However, preplanning for the near future (up to perhaps four or five years) for the accommodation of a specific subsystem already in development may be worthy of further consideration. Such near-term planning is, however, hardly a new concept or practice.

Finally, this Note also offers some lessons from past experience on the conduct of modification programs in general, whether or not they are based on a P^3I approach. Cost, schedule, and performance outcomes of past modification programs have varied considerably. These variations are related to different R&D approaches. The most favorable outcomes were experienced on programs that avoided highly concurrent development and production, allocated sufficient time and resources to proof testing, minimized technical risks by pursuing incremental advances, and provided a central coordinating management structure. In short, the "classical" pitfalls that have been identified in the development of new air vehicles should also be avoided in major modification efforts.

CONTENTS

FIGURES

TABLES

I. INTRODUCTION

In the last few decades critics both inside and outside of the Department of Defense have contended that weapon systems cost too much, take too long to develop, and too often perform poorly.[1] In response, defense officials have proposed alternative weapon acquisition strategies to improve the results of weapons policies and instituted a variety of institutional reforms. The 1970s, for instance, saw the limited return of prototyping as an acquisition strategy. The early stages of the acquisition process have been restructured with the introduction of the Mission Element Needs Statement (MENS) in 1976. The MENS requires that a new system be described in terms of the mission and not hardware performance. Lately another acquisition approach--Preplanned Product Improvement (P^3I) or Planned Lifetime Updating of Systems--has generated considerable interest.[2] The principal notion behind this strategy is the idea of _planning from a system's origins_ to incorporate performance improvements over the course of a weapon system's life.

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[1] For one of the first comprehensive studies of post-World War II acquisition problems see Merton J. Peck and Frederic M. Scherer, _The Weapons Acquisition Process: An Economic Analysis_,. Harvard University Press, Cambridge, 1962. More recently see E. Dews et al., _Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s_, The Rand Corporation, R-2516-DR&E, October 1979.

[2] See _Pre-planned Product Improvement_, Proceedings from an American Defense Preparedness Association Seminar and Workshop, April 1980 (hereafter referred to as ADPA Proceedings; some of the work done at the Workshop was later summarized in the January 1981 issue of _National Defense_); _Proceedings of the Systems Acquisition Management Conference_, American Institute of Industrial Engineers, Fall 1980; and "Time Cut Spurs New Design Approach," _Aviation Week & Space Technology_, December 8, 1980.

Improving weapon systems while the system is still in production or after the production run has been completed is certainly not new. Most systems undergo some modifications to improve their performance at regular intervals during their operational lives. Those with multiple decade lives, such as the current versions of the B-52 and F-4, differ in many ways from their initial configurations. In dollar terms, modifications are an important portion of the defense budget. In FY 1980 over $600 million was spent on modifying and improving Air Force and Navy tactical aircraft. And in FY81-FY83 tactical aircraft modifications will come to over $3 billion.

By the end of the 1970s, some defense and industry officials increasingly emphasized preplanned system modification as an alternative force modernization approach, coining the phrase "Preplanned Product Improvement" to describe what some alleged was a radical new approach. P^3I differs from the routine modification process in that it stresses <u>preplanning</u> during the initial design stage, and it is viewed as a coherent modernization strategy. In 1980 one of the five management initiatives to improve the acquisition process and its outcomes proposed by the Under Secretary of Defense for Research and Engineering, William J. Perry, specifically emphasized modifications and product improvements as an approach to force modernization and acqusition problems.[3] Among the changes the new Deputy Secretary of Defense, Frank C. Carlucci, is

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[3] The others emphasized increased use of competition, additional allied cooperation, using tailored procurement procedures, and using technology to reduce manufacturing costs. See U.S. Congress, House Appropriations Committee, <u>Department of Defense Appropriations for 1981, Part 3, Hearings</u>, pp. 21-25.

making in weapon system acquisition procedures is a specific recommendation favoring the expanded use of P^3I strategies.[4]

Despite this growing interest, the P^3I concept remains vague and ill-defined, its possible effects uncertain. Its advantages and disadvantages have been left to the realm of conjecture and speculation. Further, despite the substantial dollar size of the current modification effort and the nearly continual process of modification that systems undergo during their inventory lives, earlier modification strategies were also subjected to little policy analysis. This Note represents an effort to advance and clarify the present discussion of P^3I as an acquisition strategy and to gain some insights and lessons concerning how best to conduct modification and improvement programs. We draw on past aircraft and helicopter modification experiences to enlighten the discussion of these issues.

To provide a background and context for the following discussion, we briefly review the acquisition trends that led to the formulation of the P^3I concept. We next address the question of what the policy is supposed to mean. The wide variety of definitions of the concept must be carefully sorted out and compared if the discussion is to advance beyond its present state. In Sec. II, we examine some of the basic premises of P^3I in the light of past modification experience of military aircraft. Section III discusses lessons gleaned from past modification experience that are applicable to all major modification programs whether P^3I or not. Section IV offers some conclusions and observations.

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[4] Frank C. Carlucci, "Improving the Acquisition Process," Memorandum for Secretaries of the Military Departments, Chairman of the Joint Chiefs of Staff, Under Secretaries of Defense, Assistant Secretaries of Defense, General Counsel, Assistants to the Secretary of Defense, April 30, 1981.

SELECTED SYSTEM ACQUISITION TRENDS AND MODERNIZATION ALTERNATIVES

To clarify the concept of P^3I, we first review the factors that give impetus to the concept as a way to modernize U.S. forces. Defense analysts urging the adoption of P^3I believe that U.S. forces must modernize quickly to adequately perform their assigned missions.[5] A measure of the urgency of modernization is the growing average age of the U.S. weapons inventory. These analysts note that replacing weapons is lengthy and expensive. Moreover, several authorities contend that the process of force modernization is aggravated by budgetary fluctuations and a belief that even planned-for budget increases are not consistently fulfilled. Several factors must be taken into consideration:

- High costs of weapon systems.
- Lengthening acquisition intervals.
- Increasing age of current inventory.
- Constrained budgets.
- Pace of technological advance.

Advocates contend that P^3I offers an important method for enhancing force modernization. It grew out of the idea that product improvement modification of inventory aircraft is a quicker and cheaper way to modernize than new starts. As an acquisition strategy, however, P^3I

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[5] This section summarizes the views of P^3I advocates found in the ADPA Proceedings, the Proceedings of the Systems Acquisition Management Conference, and the arguments made in the January 1981 issue of National Defense devoted to P^3I.

applies primarily to new starts. To understand why advocates believe that new vehicles should be designed according to P³I principles, we review the arguments for modification as a force modernization strategy.

Acquisition Trends

Any force modernization alternative has to recognize the five factors identified above. First, weapon systems are an expensive investment. As Fig. 1 indicates, the real costs of a tactical aircraft have been increasing over time.[6] The average unit cost of a fighter or attack aircraft in the 1950s was $4 million, in the 1960s the average cost increased to $8.4 million, and by the 1970s the average cost was nearly 200 percent higher than in the 1950s, at $11.7 million.[7] Looked at somewhat differently, the cost of producing a pound of aircraft is nearly 500 percent more today than in the late 1940s and early 1950s (see Fig. 2). Second, budgets have not increased at a comparable rate (see Fig. 3). Third, the acquisition cycle--the time it takes to develop and field a new tactical aircraft--is increasing. The time lags seem to result not from an increase in the time spent actually

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[6] This Note examines modification issues and P³I as an acquisition strategy applied to tactical aircraft acquisitions. However, the concept also seems applicable to such other weapon systems as tanks and ships.

[7] Costs are in constant FY 1975 dollars. Costs include airframe, propulsion, electronics, armament, and other government furnished equipment and exclude R&D, operations, and investment in peculiar support and spares. The average costs are derived from average flyaway costs of the first 200 units produced. The 1950s sample includes A3D-2, A4D-1, F-89, F4D, F-100, F-101, F-102, F-104, F-105, and F-106. The 1960s sample includes A-6, A-7, F-4, and F-111. The 1970s set is made up of A-10, F-14, F-15, and F-16. G. K. Smith and E. T. Friedmann, An Analysis of Weapon System Acquisition Intervals, Past and Present, The Rand Corporation, R-2605-DR&E/AF, November 1980, pp. 140-141.

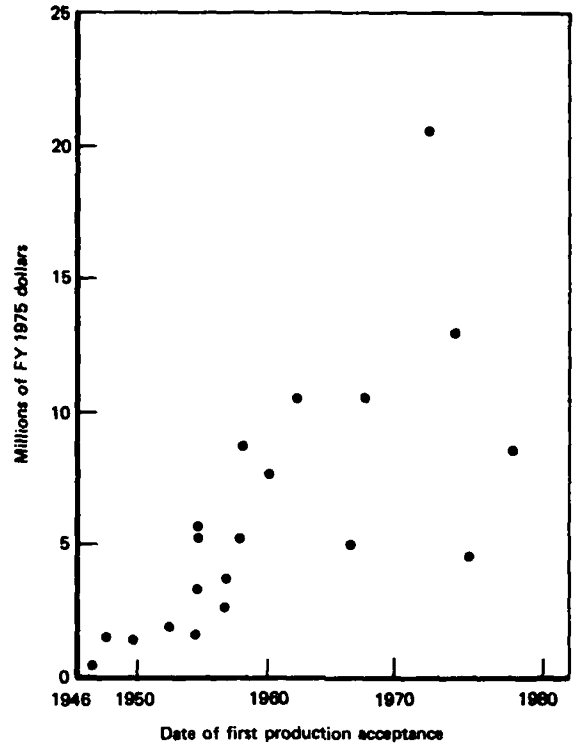

Fig. 1 — *Unit costs of tactical aircraft*

designing, developing, and testing a system--the Full Scale Development (FSD) phase--but from an increase in the concept demonstration and validation phase before FSD and the production build-up phase.[8] (See Fig. 4.)

One consequence of these trends is that our rate of force replenishment is dropping and the age of the U.S. tactical air fleet grows each year. The average age of Air Force fighter and attack aircraft in the active inventory in FY 1960 was 3 years; in FY 65, 5

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[8] Equivalent to the period between Milestone I and Milestone II as delineated in DoD Directive 5000.1.

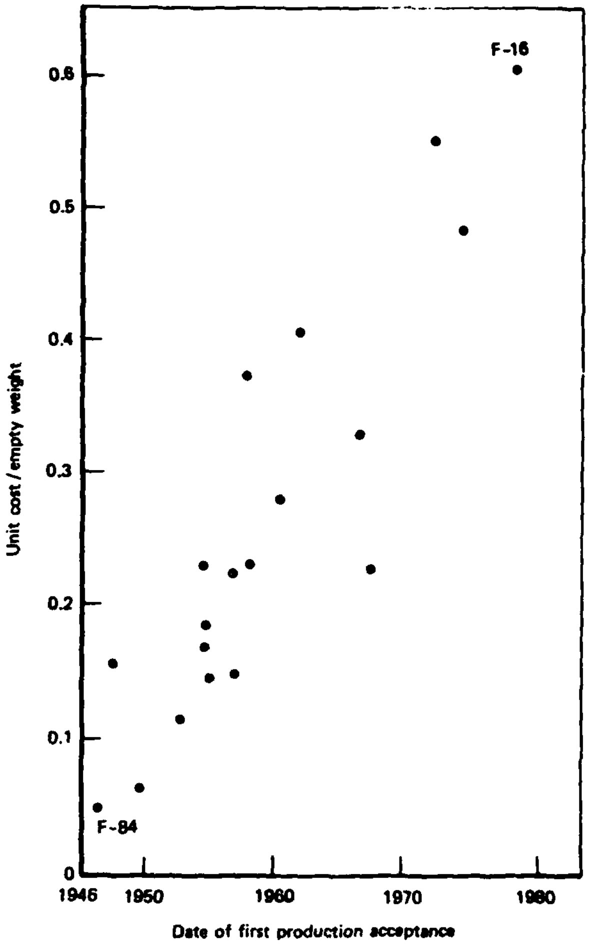

Fig. 2 — Cost of producing a pound of aircraft

years; in FY 70, 6 years; in FY 75, 7 years; in FY 80, 8 years,; and is projected to be 10 years in FY 1985.[9]

Finally, research in the rate of basic air vehicle technology advance (engine-airframe technology rather than avionics or munition

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[9] USAF Statistical Digest and Aerospace Vehicles and Flying Hours, PA82-1.

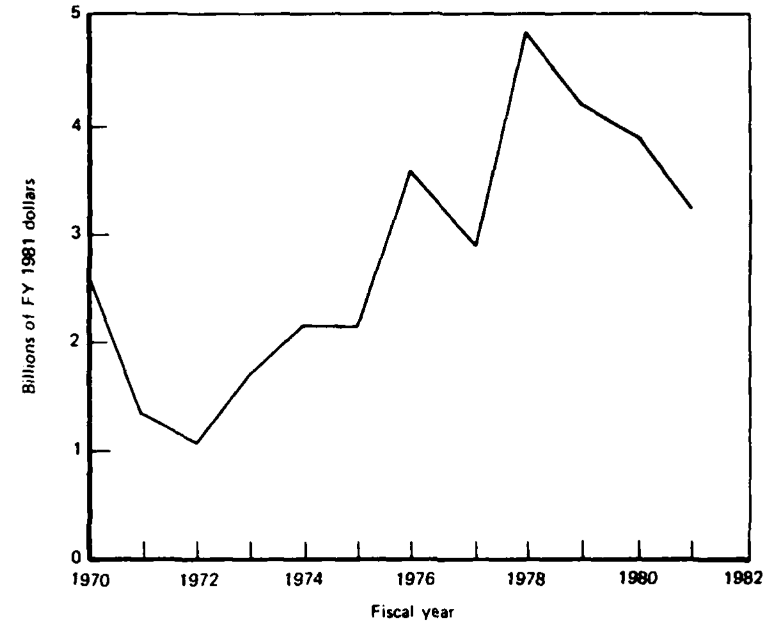
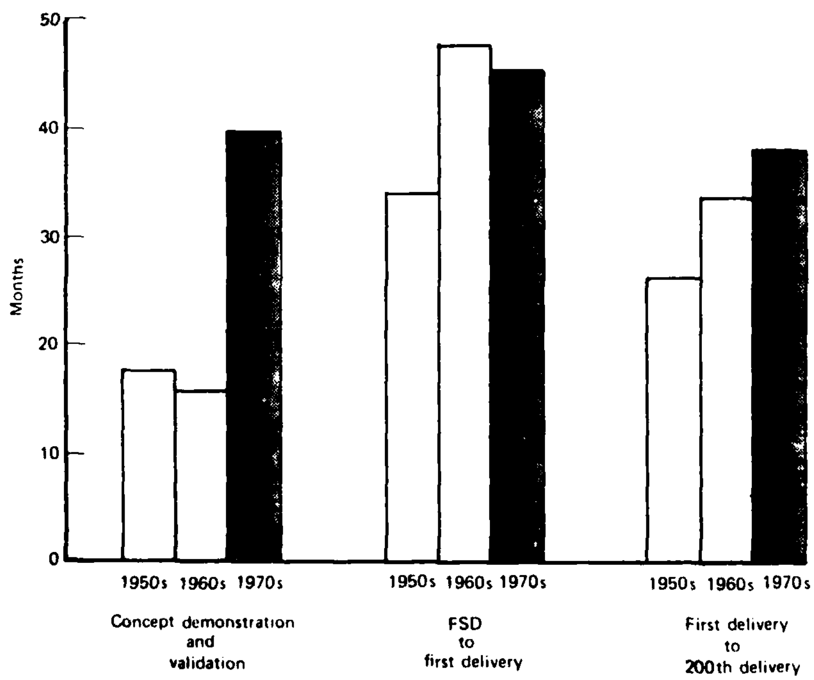


Fig. 3 — U.S. Air Force tactical aircraft procurement budget



SOURCE G.K. Smith and E.T. Friedman, *An Analysis of Weapon System Acquisition Intervals, Past and Present*, R-2605-DR & E/AF, November 1980.

Fig. 4 — Selected acquisition intervals by decade

technology) suggests that the pace of that advance is declining. In other words, to make an absolute air vehicle performance improvement comparable to that made between the F-4 and F-15 might take two to five times longer next time.[10] This implies the United States cannot rely on air vehicle technology to yield major performance improvements. Other areas of technology, such as electronics, seem to be moving at a more rapid rate, which suggests that rather than developing wholly new airframes, we could achieve greater performance leverage by investing in electronic improvements: modernization through modification instead of new airframe developments.

Modernization Alternatives

One option to deal with this situation might be to replace systems on a less than one-for-one basis and allow force size to decline. Another option might be simply to let the inventory grow older. Such options would be disturbing to many defense officials. The Soviet Union already maintains an inventory of roughly 1500 more tactical aircraft than the United States does. Further, the Soviets add more aircraft on average each year to their active inventory than does the United States.[11] In the European theater, the Warsaw Pact maintains nearly

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[10] See William L. Stanley and Michael D. Miller, Measuring Technological Change in Jet Fighter Aircraft, The Rand Corporation, R-2249-AF, September 1979.

[11] Since 1974, the United States has maintained just over 2800 tactical combat aircraft while the Soviet Union's inventory has varied between 4255 and 4585 aircraft. Although Soviet additions to their inventory have fluctuated more than U.S. additions between 1975 and 1979, the United States added an average of nine aircraft per month to its inventory and the Soviets added an average of 46. See John M. Collins, U.S.-Soviet Balance, Concepts and Capabilities 1960-1980, McGraw-Hill, New York, 1980.

2000 more tactical aircraft than does NATO--a 1.7 to 1 advantage.[12] In the past the United States relied on the technical superiority of its aircraft to counter the greater numbers of Soviet and other Warsaw Pact aircraft. Unfortunately the United States can no longer comfortably rely on technical superiority to make one American aircraft "worth more" in air combat than one Soviet aircraft. A recent examination of U.S. and Soviet fighter aircraft technology found that neither nation has a technological advantage over the other.[13] Furthermore, an Air Force test of a few years ago designed to determine how influential numbers of aircraft were in air combat engagements pitted highly capable F-15 aircraft against the less sophisticated F-5 and found that, at least under the test's conditions, sophistication mattered less and the number of aircraft mattered more in determining air combat success than expected. These results suggest that allowing force size to decline by replacing systems on a less than one-for-one basis will probably result in less U.S. defense capability, at least in terms of tactical airpower.

The United States might choose to purchase enough tactical aircraft to replace current systems one for one or even at a greater ratio. Assuming a constant force size, and that the United States maintained an average active inventory design age of five years, the Air Force would consistently have to procure at least 600 tactical aircraft each year.[14] The estimated cost of such an effort would come to about $7

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[12] See _The Military Balance 1980-1981_, International Institute for Strategic Studies, London, pp. 113-114.

[13] See Stanley and Miller (1979).

[14] This calculation assumes that a new design would be introduced every five years. More frequent introduction of new designs would decrease the number of units to be procured each year but would increase the rate of research and development investment.

billion annually. Air Force spending on tactical aircraft has not sustained such a level of funding (see Table 1). Moreover, the new programs to replace the systems in the current inventory would also require substantial development funding. Recent new development programs have been expensive. The A-10's R&D costs approached $500 million, the F-16's were nearly $1 billion, and the F-15's totaled just over $2 billion.[15] Thus, combining high development costs and escalating unit costs means that budget increases to support this alternative will have to be consistently large over several years.

Table 1

AIR FORCE TACTICAL AIRCRAFT PROCUREMENT BUDGET

Fiscal Year	Funding in FY81 Dollars[a]	Procurement Quantities
1970	2522	230
1971	1281	124
1972	1042	145
1973	1683	114
1974	2170	122
1975	2157	189
1976[b]	3548	205
1977	2859	208
1978	4886	346
1979	4262	379
1980	3967	391
1981	3238	270

SOURCE: USAF F&FP.
[a] In millions of dollars.
[b] Includes Transition Quarter.

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[15] Jon S. Eckert, "Trends in U.S. Air Force Tactical Fighter Life Cycles," Peace Studies Program Occasional Paper No. 11, April 1979.

Despite the present planned increases in defense spending for FY 1983, reasonable planners might question whether they will come to pass. As Table 2 indicates, funding plans are not always fulfilled, and sometimes the actual funding is less than the planned funding. Prudent defense planners cannot be entirely confident that all increases will be carried out.

Another approach to high replacement costs is to produce new, less costly (probably lighter) systems. Such cost reductions would have to be significant. According to one assessment, a one-third reduction in unit costs would be required to maintain current force levels and funding rates.[16] Reduced cost (and weight), however, implies, according to some authorities, reduced performance.[17] Accepting

Table 2

ACTUAL VERSUS PLANNED FUNDING

Aircraft	Actual/Planned Funding[a]
A-10	.88
F-15	.96
F-16	1.25

SOURCE: DOD Annual Reports.
[a] Actual Funding = t; Planned Funding = t + 3. A ratio of 1.00 indicates that planned funding equaled actual funding.

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[16] See Hy Lyon, "Pre-Planned Product Improvement," National Defense, January 1981.
[17] For instance see George Spangenberg, "Cheap Fighters--The Impossible Dream," Armed Forces Journal International, April 1974.

significant declines in aircraft performance would be a risky modernization strategy.

These concerns have led analysts to look for other modernization alternatives. One way to modernize U.S. forces is to continue to upgrade systems through product improvement. Modification is generally held to be less costly than a new start, and it can significantly improve performance. P^3I is being proposed as a strategy applicable to new starts that would facilitate this process.

PREPLANNED PRODUCT IMPROVEMENT: WHAT IS IT AND WHAT WILL IT DO?

Definitions of P^3I

As yet no widely accepted definition of P^3I has emerged. Indeed it is unclear to some observers whether P^3I differs substantially from current practices of periodically upgrading the configuration of inventory systems. However, one key element runs through most definitions of P^3I: design of a system from its origins to incorporate future performance enhancements. Current DoD policy guidelines distinguish between the use of P^3I as applied to a new system and in the context of an ongoing program.[18] In the former case P^3I is implemented "by including growth potential in the basic design to accommodate future evolutionary improvements and by making the architecture (or structure)

[18] See Frank C. Carlucci, "Improving the Acquisition Process Through Pre-Planned Product Improvement," Memorandum for Secretaries of the Military Departments, Chairman of the Joint Chiefs of Staff, Under Secretaries of Defense, Assistant Secretaries of Defense, General Counsel, Assistants to the Secretary of Defense, July 6, 1981.

of the system sufficiently flexible to accommodate modular changes." The consensus definition emerging from the ADPA Proceedings was:[19]

> P^3I is a systematic and orderly acquisition strategy beginning at the system's concept phase to facilitate evolutionary . . . upgrading of a system throughout the life cycle . . . (the) baseline consideration design shall permit growth to meet the changing threat and/or take advantage of significant technological . . . opportunities.

Another definition notes that a P^3I system is: "designed, both initially and periodically thereafter, as much for change as it is to achieve the best possible solution to the known need."[20] A graphic description of this concept is presented in Fig. 5.

According to most definitions, P^3I differs significantly from the current modification process. First, P^3I is often perceived as a distinct force modernization strategy. It considers only quality improvements to a system, not changes made to improve flight safety, correct deficiencies, or meet initial performance expectations.[21] Enhancing the quality of an aircraft means not only performance improvements (higher thrust engines, better avionics) but also mission changes and reliability and maintainability improvements. Second, P^3I entails planning for future system performance upgrades in the initial design of the air vehicle.

As a theoretical concept the P^3I strategy fundamentally differs from current modification practices in that it is a coherent modernization strategy and it stresses preplanning for modifications

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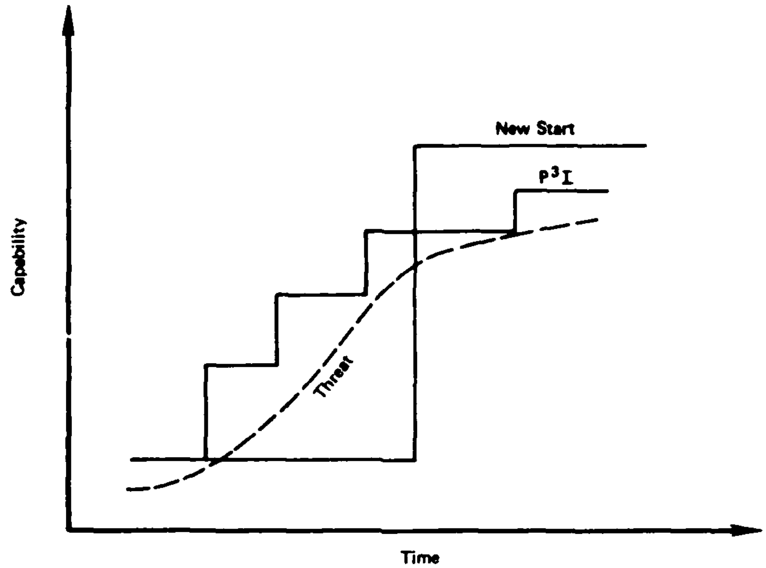
[19] Lyon, "Pre-Planned Product Improvement," p. 22.

[20] Cited in "Time Cut Spurs New Design Approach," p. 57.

[21] In terms of the modification categories described in Air Force Regulation 57-4 we are considering Class V Modifications



SOURCE: *American Defense Preparedness Association, Proceedings,* April 1980, p. 118.

Fig. 5 — P^3I vs. a new start

during system design. Nonetheless, most definitions are rather broad and vague, and they vary in emphasis. In our view they subsume at least three separate notions of P^3I, which are described below. It is probably most accurate to speak of a spectrum of modification practices, with current ad hoc practices entailing no preplanning (beyond basic good design rules) at one extreme and the most radical forms of P^3I at the other.

The first and most far-reaching P^3I approach does not address <u>specific</u> future air vehicle modifications. It requires initially designing the aircraft to anticipate and facilitate <u>any</u> <u>and</u> <u>all</u> <u>kinds</u> of likely modifications that may be deemed necessary over the inventory

life of the aircraft. Improvements would be undertaken both on the production line and after production was completed. We call this type of preplanning "nonspecific" P^3I.

"Subsystem-specific" P^3I is a more modest approach. It is more short term in orientation. As with nonspecific P^3I, modifications are anticipated in the aircraft's initial design stages. However, only the first generation of modifications is planned for. These particular improvements include mainly specific subsystems already in development but too technically immature to be incorporated into the first operational version of the aircraft. These improvements would probably be made mainly on the production line. The DoD guidelines mentioned above and most other discussions of P^3I fail to make this conceptional distinction. As we argue later, this distinction is important because there are major differences in the degree of practicality between nonspecific and system-specific P^3I.

Another modest form of P^3I applies more to subsystems than to airframe designs. This calls for designing standardized subsystems, particularly avionics, with standardized interfaces. Such an approach permits the adoption of a "building block" approach, where, for example, new components can be easily added to or substituted for older components in an avionics subsystem. This type of P^3I has been dealt with extensively elsewhere, at least for avionics subsystems.[22] Although DoD guidelines also include this concept in their broad definition of P^3I, we limit our analysis to those forms of P^3I that

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[22] See D. W. McIver, A. I. Robinson, H. L. Shulman, with the assistance of W. H. Ware, A Proposed Strategy for Acquisition of Avionics Equipment, The Rand Corporation, R-1499-PR, December 1974.

emphasize preplanning the overall air vehicle design. In this context, we examine the first two forms delineated above, directed toward nonspecified and specified future modifications.

P^3I contrasts sharply with the types of quality modifications prevalent today, which might be called ad hoc improvements. This sort of improvement was not specifically anticipated in any sense during the system's development but nonetheless could be incorporated into the aircraft sometime during its inventory life. The majority of all modifications made today fall into this category.

P^3I in its extreme nonspecific form entails making provisions to incorporate a series of engine and avionics upgrades not only a few years away but as many as 15 years away as well. Such an approach to aircraft design has never, to our knowledge, been attempted. The F-14 program represents the less ambitious class of preplanning that we call subsystem-specific improvements. Provisions were made in this program to add a specific new engine after the first 70 F-14s were procured. The upgrade would have occurred within a year or two of the initial delivery of the F-14. The series of improvements that the F-4 has undergone is typical of the ad hoc class of improvements. No planning for future improvements had been undertaken in the F-4's initial design and development stages, beyond basic good design rules.

Expected Results of Pursuing a P^3I Strategy

Advocates of a P^3I strategy hypothesize that it will take less time and money to upgrade and modernize a P^3I system than to modernize a system not designed for growth. By planning for system upgrades ahead

of time they assume costs and delivery times can be cut, particularly compared with costs and delivery times of a new start. A P^3I program also implies a longer useful life than a conventionally designed system. The ability to upgrade the system easily should extend the system's life and thus put off the expense of beginning a new program for a few years. Such an approach also provides increased flexibility to take advantage of new technological opportunities in avionics and armaments, which should also insure that the United States does not have to rely on outdated tactical aircraft.

The degree of new technology embodied in a new system is generally thought to affect the ability of that system to meet initial cost, schedule, and performance goals.[23] The United States has often sought for a variety of reasons to incorporate the latest technological developments into its weapon systems.[24] The result is that such systems sometimes do not perform as expected, cost more than expected, and are delivered later than expected. P^3I advocates believe this strategy allows the incorporation of advanced technology subsystems into older airframes to take advantage of the added performance, but only after these subsystems have matured. The initial P^3I system may not take advantage of all the latest technologies and may not have the most advanced performance _thought_ possible. But the system is able to perform, it is hoped, as expected. In this way overall force capability

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[23] See R. Perry et al., _System Acquisition Strategies_, The Rand Corporation, R-733-ARPA/PR, June 1971.

[24] On this point see R. G. Head, "Technology and the Military Balance," _Foreign Affairs_, April 1978; and R. Perry, _The Interaction of Technology and Doctrine in the USAF_, The Rand Corporation, P-6281, January 1979.

may improve because reliable systems are fielded. Moreover, if the maximum performance advance is not sought, R&D risks may be reduced with the result that initial cost and schedule goals might be met more consistently too. As the technology matures, it can be incorporated into the airframe through modification with minimal reliability and cost problems.

SUMMARY

Many observers believe modification alternatives, especially P^3I, offer attractive options to deal with the urgent need to modernize U.S. forces, as well as the difficulties imposed by high weapon system costs, lengthening acquisition intervals, constrained budgets, and the decelerating pace of air vehicle advance. One theme runs through all definitions of P^3I:

- Designing a system, <u>from its origins</u>, to incorporate future performance improvements, over part or all of the system's full inventory life.

A P^3I program differs in several ways from the traditional ad hoc modification process because it is a planned process to regularly incorporate quality improvements into aircraft over the system's lifetime. To its supporters a P^3I program seems to offer several potential advantages:

- It can provide needed capability faster and cheaper than a new start or a conventional modification program.

- Such systems will have longer lives than conventionally designed systems.

- P^3I programs will tend to embody less R&D risk than conventional systems because there is less compulsion to include the latest technology.

- P^3I systems will not have the most advanced performance thought possible but rather incorporate only the latest reliable improvements into the system.

II. PREPLANNING FOR FUTURE IMPROVEMENTS

The discussion of P^3I has advanced various broad definitions of the concept and several hypothesized advantages of this alternative acquisition strategy. However, little evidence has been brought to bear to test the concept's premises. In this research we have attempted a limited test of the feasibility of applying the policy and the likelihood of achieving the projected benefits by exploring past modification programs and activity similar to P^3I.

We decided to review major quality improvement modification programs for military aircraft conducted since World War II. Our sources of information included original program documents, discussions with industry personnel when possible, and published and private accounts of the programs. Given the wide variety of programs examined, some dating back to the early 1950s, it is not surprising that the data varied considerably in quality and quantity. These variations in most cases precluded precise, quantified assessments and cross comparisons of the programs examined. Nonetheless, we believe the information we gathered is sufficient to support some limited but useful conclusions.

We examined the theme that any P^3I effort must incorporate--preplanning. Specifically we hoped to gain some insight into the following questions:

- Is there evidence from past modification experience that suggests preplanning would significantly enhance future modifications?

- In what ways, and to what extent, can designers adequately preplan for future system upgrades?

After an extensive survey of past modification experience we are unable to answer these questions conclusively. However, our research raised serious issues that must be further addressed before P³I is embraced without reservation. A careful review of the design origins of air vehicles that have been modified often and have enjoyed long inventory lines, combined with an examination of the few systems we could uncover that apparently incorporated an approach similar to P³I, plus a look at other modification programs, led us to conclude that:

- Nonspecific preplanning beyond a fairly short time horizon may be impractical.

- Currently accepted good design practices (which usually entail providing for future growth) may already represent the practical limits of nonspecific preplanning.

- System-specific preplanning for a short time horizon, while entailing certain risks, may be worth pursuing further.

CASES EXAMINED

To examine issues raised by P³I, we studied a diverse group of modification programs.[1] We began by reviewing experiences of often modified and remarkably long-lived aircraft. This, we expected, would yield some insight into the design and development practices that accounted for these systems' adaptability and long inventory lives. We

[1] We included only performance quality improvement or mission-change modification programs, roughly equivalent to current Air Force Category V modifications. Modification programs for improved safety or to bring performance up to original specifications were excluded.

also searched for cases of preplanned modification activity--programs that in some way anticipated and planned for making quality improvements in the system's initial design stages. Unfortunately this has rarely occurred in the past; in our survey only the F-5, F-14, and N-102 programs[2] entailed any form of anticipation of future modifications, either of the nonspecific or specific type. Indeed none of these really represent pure examples of nonspecific P^3I. To supplement these cases we examined other examples of major modifications. The various cases also provided a rich data base from which to draw some insights into the conduct of major modification programs in general. (The appendix summarizes case histories of the most important programs examined.)

Table 3 lists the characteristics of the most important discrete modification efforts examined along with the four often-modified aircraft with long inventory lives that we studied in most detail. The cases include a broad based and diverse mix of aircraft from all three services. We examined major modifications such as the conversion of the B-57B bomber to a high altitude reconnaissance aircraft that required new wings, engines, and avionics, and more modest efforts such as the avionics upgrades incorporated into the F-4E. Finally the cases include several different types of quality improvements. Performance enhancements, such as the addition of new avionics and engines, are included as are programs whose goals were reliability enhancements or mission changes.

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[2] The N-102 Fang was a lightweight fighter design proposed by Northrop in the early 1950s. (See the appendix for further details.)

Table 3

CHARACTERISTICS OF CASES EXAMINED

Program	Goal	Modifications Made: Avionics	Engine	Airframe
I. Some Preplanning				
F-5E	Performance enhancement	X	X	
F-5G	Performance enhancement		X	
F-14A	Performance enhancement	X	X	
N-102	Performance enhancement		X	
II. No Preplanning				
A-7A	Mission change	X	X	X
A-7D	Performance enhancement	X	X	
CH-47D	Reliability		X	X
F-4E	Performance enhancement	X		
F-4M/K	Performance enhancement/ Offset	X	X	
RB-57D	Mission change	X	X	X
RB-57F	Mission change	X	X	X
III. Long-Lived, Often-Modified Aircraft				
A-4A to A-4S	F-4A to F-4S			
B-52 to B-52H	F-5A to F-5G			

AIR VEHICLE IMPROVEMENT EXPERIENCE

An essential element of a P^3I strategy is the ability to provide an airframe with the potential for future upgrades to an extent beyond current routine design practices. To assess this aspect of a P^3I strategy we examined (1) the initial design and development stages of several systems that have been especially robust in terms of inventory life and number of quality improvements and (2) programs that seemed to have in some way anticipated future modifications in their initial designs.

In the class of particularly robust airframes are the A-4, B-52, F-4, and F-5 programs. Each system remains in the inventory today, although the A-4, F-4, and F-5 were designed in the mid-1950s and the B-52's design stretches back to the late 1940s. Did the original airframe designers provide for future modifications? Given the changes and modifications these systems underwent was it reasonable and within the ability of system's designers to anticipate or plan for future improvements? If so, are there any guidelines applicable to designing systems with growth potential?

The A-4 Program

The A-4 was the Navy's replacement for the A-1 (or as it was formerly known the AD-1), a carrier based dive bomber and torpedo carrier. The Navy wanted an aircraft that could deliver larger payloads with a higher speed than the piston-engined A-1. The A-4 proved to be an extremely light, reliable, and long-lived system. Initial design work began in 1953, the first delivery occurred in 1955, and the last

A-4 (the A-4M) was delivered in 1979; new modifications of older A-4s are still entering the active inventory. Nearly 20 different versions of the A-4 have been produced. Most of the improvements have been to increase engine thrust, improve avionics systems, and increase the weapons payload from that of the basic version of the A-4. The basic mission of the A-4 has remained largely unchanged--a carrier-based attack aircraft.

The designers of the A-4 attempted to build the lightest and simplest aircraft they could; they made no special provisions for incorporating new engines, better avionics, or larger ordnance loads.[3] Ironically, the design objectives were in some respects totally at cross purposes with the P^3I concept in that the designers wanted the lightest, simplest, smallest aircraft possible. As a result, there was not enough room to fit the additional avionics incorporated in the A-4F into the basic A-4 airframe, and the fuselage had to be enlarged with a "camel's hump" behind the cockpit to accommodate the necessary subsystems. The long life and many modifications of the A-4 seem to have more to do with the fact that it is a robust, inexpensive airframe, easy to maintain, performing a mission that has changed little since World War II.

Presumably the A-4 could have been designed with more space in the airframe and other provisions that might have facilitated future modifications. However, that would have had to be traded off against the design objectives of simplicity, low cost, small size, and low

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[3] For more on the design origins of the A-4 see E. H. Heinemann, "Design of Lightweight, Simplified Combat Aircraft," Interavia, Vol. X, No. 3, 1955, pp. 172-178. Heinemann was the principal designer of the A-4.

weight. Had some of these latter objectives been compromised, some of the very attributes that have contributed to the aircraft's usefulness, hence long inventory life, might have been lost.

The F-4 Program

We found no evidence that the F-4 was designed with the prospect of future modifications in mind. The F-4 initially (F-4A and F-4B) was designed as a fleet defense fighter, able to fly 250 nautical miles away from a Navy carrier, stay on patrol for two hours, destroy any enemy aircraft with missiles, and return to the carrier. The Air Force eventually procured the F-4 (the C version) to serve as a multipurpose tactical aircraft. In 1964 the Air Force modified the F-4 (to the D version) to enhance its ground attack abilities. The McDonnell engineers designing the fleet air defense aircraft in the mid and late 1950s never envisioned the ground attack role played by the F-4D.[4]

Originally the contractor had submitted a fighter ground-attack design, but the Navy rejected it in favor of a design specifically optimized for the fleet air defense role. The F-4 was never expected to enter combat at high gross weights or to perform tight turns below 10,000 feet, and the Navy and McDonnell were not very disturbed about the F-4's tendency to stall under such conditions. However, the Air Force F-4s used in Southeast Asia in the air-to-ground role had to enter combat fully loaded and perform tight maneuvers at low altitudes to

[4] For a description of the evolution of the F-4 until 1977 see W. T. Gunston, _F-4 Phantom_, Charles Scribner's Sons, New York, 1977. On the Air Force decision to buy the F-4C in favor of the more expensive F-105, see R. G. Head, "Decision Making on the A-7 Attack Aircraft Program," D.P.A. dissertation, Syracuse University, 1971, pp. 156-165.

fulfill their missions. The stall problem was corrected by maneuvering slats, among the many modifications made to the F-4E. DoD adopted the F-4 for Air Force use because of performance and service standardization reasons, not because it was inherently an easily modified aircraft. In fact, several of the major modifications caused considerable difficulty.

The B-52 Program

The B-52 emerged out of an Air Force requirement of the late 1940s for a long range (5000 miles), high speed, and high altitude (300 mph at 35,000 feet) bomber. Yet the strategic missions considered for the B-52 in the 1960s required it to operate at low altitudes. The B-52s were extensively modified to withstand the stress of low level operations. It seems unlikely Boeing's designers could have planned for or anticipated such a modification in the late 1940s and early 1950s.

The F-5 Program

Another system with a long active life and extensive modification record is the Northrop F-5 aircraft. Unlike the A-4, F-4, and B-52, this aircraft shows indications that designers at the Northrop Corporation did anticipate some future modification activity. The F-5 aircraft was developed with corporate funds for sale to European and Asian air forces as well as to the U.S. Air Force. It was reasonable to expect different air forces to have different needs and to want different combinations of engines and avionics. Some space was set aside in the airframe nose to provide growth capability for alternative armament radar and reconnaissance version equipment layouts, and engines

were installed in a way that permitted substitution of different models with a minimum of airframe modification.

The F-5 program, specifically the strategy to gradually improve the A version's avionics, is the only example we found where preplanning for specific future performance improvements was actually carried out. In addition, the improvements were successfully implemented through a strategy of incrementalism. In the late 1960s several nations urged Northrop to improve the basic F-5A's avionics systems. As mentioned above, extra space was included in the design of the F-5 nose. Northrop recognized that no one nation could fund the development of a completely new avionics suite, so it planned to improve the system gradually over time. The first enhancement was incorporation of a lead computing gunsight and Head Up Display in the Canadian version of the F-5A. The F-5E included many improvements, and in 1975 Saudi Arabia funded others.

Preplanning room for growth and planning for incremental improvements facilitated the modification process and reduced R&D risks and uncertainties in the development of the F-5's avionics systems. However, the overall complexity and sophistication of the subsystems were below that often seen on U.S. Air Force fighters. In addition, it is unclear to what degree Northrop's design approach differed significantly from the common practice of providing room for growth in airframes.[5]

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[5] "Growth Potential" has been a factor routinely included in the evaluation criteria of past RFP's to industry. For example, it is listed as an evaluation factor for the Advanced Medium STOL Transport RFP written over a decade ago.

The F-14 Program

The F-14 is the only other aircraft program that we have been able to identify in which some preplanning or anticipation of future modifications seems to have occurred. The Grumman F-14 airframe was originally designed to facilitate installation of a special higher thrust engine then in development, and later enhanced avionics. Initially, according to the plan developed by the Navy, the F-14A would be purchased with the TF-30 engine, but the majority of the first F-14 buy would be F-14Bs equipped with the more powerful F401 engine, the Naval version of the F100 engine being then developed for the Air Force F-15. Another version of the F-14, the F-14C, would later be procured and include an improved fire control system and enhanced reliability and maintainability.

The F-14 emerged out of Navy concerns that the proposed F-111B would not be able to adequately perform the fleet air superiority mission. As a result studies were initiated in 1967 and these studies concluded that the new fleet air superiority fighter should combine an advanced airframe with the TF-30 engine and AWG-9 Phoenix missile system both then in development for the F-111B. The mood of Congress at the close of the 1960s forced the Navy to stress low-technology risk in their development plan. Thus the new fighter would use state-of-the-art components. At the same time the design would provide for upgrading with more advanced subsystems yet to be developed. Instead of seeking the maximum possible performance advances, the Navy decided to use systems already in development, believing they would be less risky technologically and available sooner than such undeveloped systems as the F401 engine.

Unfortunately, developing the F-14A proved to be a more difficult task than initially thought. Cost growth, schedule slippage, and technical difficulties on the airframe, the TF-30 engine and the advanced technology F401 engine led the DoD to postpone the purchase of the F-14B indefinitely. Although the Navy has attempted to reverse this decision since 1971, its efforts have been in vain, and the hoped-for benefits of preplanned product improvement have not been realized.

SUMMARY

The most far-reaching concept of P^3I is based on the premise that a designer can anticipate needed improvements or possible changes in requirements well into the future with enough specificity to allow the initial version of the aircraft to be designed to accommodate these improvements, or that the designer can develop a specific new set of design rules beyond currently accepted good design practices that would imbue air vehicles with a much higher degree of inherent modification flexibility than is currently the norm. Our examination of the limited experience with relevant modification efforts of the past suggests that preplanning very far into the future is an unworkable concept.

In only two programs we examined, the F-5 and F-14, did the designers appear to have specifically provided for future growth in system capability. Furthermore, these cases entailed short time horizon forecasts of improvements, analogous to what we have termed subsystem-specific P^3I. The designers did not attempt to anticipate improvements more than four or five years in advance, and even then the subsystems

considered for incorporation were already under development. This statement is supported by our investigation of various other design proposals that were similar to P^{3}I but were never funded, such as the Northrop N-102 Fang, which was to be designed to facilitate the installation of a succession of four different engines, all already under development (see the appendix).

A survey of some of the longest lived aircraft programs in the current U.S.inventory shows that few systems revealed any indications of preplanning, and that was mainly directed to possible near-term substitution of equipment already under development. In no case did such preplanning look beyond the immediate operational mission of the aircraft. The designers of the A-4, F-4, or B-52 could hardly have conceived the changes in requirements or the array of improvements later incorporated into each weapon.

No common approach beyond basic good design rules seems to have been applied to all these aircraft to suggest why they have been successfully modified so many times.[6] Indeed, the A-4's designers consciously attempted to eliminate room for growth. The long lives of these aircraft seem based mostly on happenstance and the fact that they are generally sound, useful designs. If three of four particularly long-lived, often modified systems did not plan for future upgrades, then perhaps preplanning, even if a designer could accurately predict future modifications, may not matter very much. Unplanned systems may

[6] Recently, some designers have postulated a highly modular, building-block approach to avionic system architecture. If that concept proves practical, it might constitute a new and innovative design practice that would truly facilitate the P^{3}I objectives. Such an outcome must remain speculative at this time.

achieve the same long life and undergo capability enhancements just as well as preplanned systems.

The examples of activity similar to P^3I all were restricted to narrow circumstances. The designers of the F-14 forecast improvements only a few years ahead. All of the subsystems they hoped to incorporate into aircraft were in development at the time. Indeed, it is unreasonable to expect designers to foresee all the future missions their designs may be required to fulfill and all the subsystems that may be incorporated into the airframe. Preplanning of the type required to carry out this more limited notion of subsystem-specific improvements may be worthwhile.

These cases highlight some potential problem areas. As in the cases of the F-14 and the N-102 proposal, there will always be concern that initial versions will not perform optimally, either because the most advanced subsystems possible have not been incorporated, or because the air vehicle design has been compromised to facilitate future modifications. In addition, the F-14 case illustrates that there is considerable risk that the additional money invested in R&D up front to promote a P^3I design may prove to have been wasted if, for whatever reasons, the modification is never made.

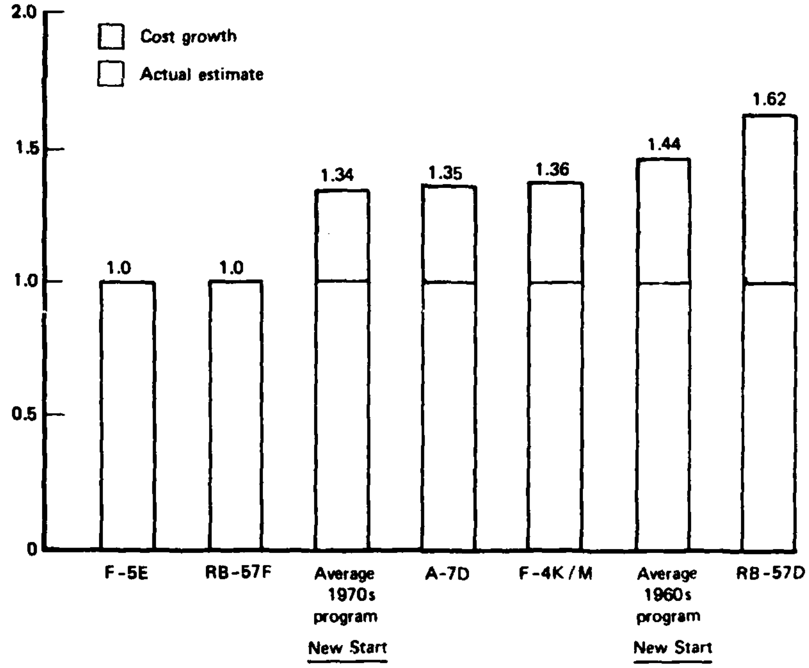
III. MODIFICATION R&D APPROACHES

In reviewing past modification experiences we were struck by the wide variation in program outcomes in terms of meeting initial cost, schedule, and performance goals. Figure 6 reflects some of the variation in expectations and results in several modification programs in terms of costs. This figure also indicates the variations of modification outcomes compared to typical new starts of the 1960s and 1970s. Table 4 summarizes the differing outcomes of the major modification programs examined.

The rather wide variations in cost, schedule, and performance outcomes uncovered by our examination of various modification programs, combined with the observation that many of the sample programs were conducted quite differently from one another, suggest that certain approaches to modification R&D may be preferable to others. A comparison of several of the cases in our sample reveals pitfalls worth avoiding in modification programs. Whether or not the concept of P³I is adopted as a force modernization strategy, modifications of inventory aircraft are likely to continue as before and rank as important programs in dollar terms. The insights gained from our examination of the conduct of past modifications programs seem worthy of Air Force attention, no matter what the outcome of the current P³I debate.

CONCURRENCY: RB-57D & F

Perhaps the most revealing comparison within the case study sample is between the RB-57D and the RB-57F programs (see Table 5). Both



Sources: Program documents and E. Dews et al., *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, The Rand Corporation, R-2516-DR&E, October 1979.

Fig. 6 — Cost outcome variations

Table 4

MODIFICATION OUTCOMES

Program	Outcome	Observations
A-7D	Mixed	High costs, schedule slippage
CH-47D	?	Not completed
F-4E	Mixed	Unstable funding, vague authority
F-4M/K	Failure	High costs, delayed, poor performance
F-5E	Success	Met cost and exceeded schedule goals
F-14	?	Not yet implemented
RB-57D	Mixed	High costs, performance, problems, delays
RB-57F	Success	Met cost, schedule and performance goals

entailed gross modification of the wing and incorporation of new engines and avionics on the basic B-57B medium attack bomber. Both programs, undertaken about eight years apart, consisted of the same type of modifications of the same basic aircraft for the purpose of performing very high attitude reconnaissance. Despite the remarkable similarities, cost, schedule, performance, and reliability outcomes varied considerably. These variations were clearly linked to the radically different modification R&D approaches adopted in the two programs.

The Air Force began the RB-57D modification program in mid-1954; a fundamental rationale for the program was that modification would lead to operational capability much sooner than would a new start. Although this assumption proved correct, the RB-57D schedule slipped about 20

Table 5

COMPARING THE B-57B, RB-57D, AND RB-57F PROGRAMS

	B-57B	RB-57D	RB-57F
Mission	Med.Tac. Bomber	Hi.Alt. Recon.	Hi.Alt. Recon.
Wing Span (ft)	64	106	122
Empty Weight	26,800	33,000	36,000
Engines	2 J65-5	2 J57-37A	2 TF-33-11A & 2 J60-9 [a]

[a] The two J60-9 engines were small auxiliary turbojets mounted outboard from and supplementing the two main TF-33-11A turbofan engines.

percent from project go ahead to first flight. Even worse from the Strategic Air Command's perspective, the delivery schedule slipped by approximately 50 percent. Compared with the contractor's original estimate for R&D plus six aircraft, program costs rose by well over 100 percent. Although the RB-57D performed largely according to expectations, its operational history was plagued with reliability difficulties, including major wing fatigue problems; engine flameout; wing tank fuel leakage; and problems with the horizontal stabilizer system, fuel controls, and aircraft power systems.

The second program, inaugurated in 1962, experienced much more satisfactory outcomes. Not only did the RB-57F program avoid schedule slippage, it required only about two-thirds the time to achieve a first flight as had been allocated in the original preslippage RB-57D

schedule. The F program experienced no cost growth and cost only slightly more than the D program. Finally, the RB-57F surpassed its predecessor in top ceiling, payload, high altitude maneuverability, and operational reliability.

A striking difference in these two programs that could explain the variation in outcomes was the R&D approach. If anything, the F program may have entailed more technological risk in that a much larger wing, a new crew ejection system, and new high altitude reconnaissance equipment were developed. The RB-57D contractor experienced difficulties with subcontractors and with program changes made by the Air Force, yet these do not seem to have substantially affected program outcomes. Instead, radically different R&D approaches involving concurrency and testing probably contributed heavily to the variation in program outcomes.

All aspects of the RB-57D R&D and production program were conducted simultaneously in an effort to achieve operational availability as quickly as possible. The manufacturer received a single contract covering both R&D and production. Production engineering and preparations commenced at the very beginning of development. The contractor began construction of the first production aircraft only weeks after the first flight of the first prototype. More than half the production run had been completed when flight testing revealed a fundamental design flaw in the wing requiring an extensive retrofit program. Indeed, flight testing was still under way when the last production RB-57D was completed. At least 60 percent of production aircraft eventually required retrofit modifications because of experience gained from flight testing.

It seems reasonable that a phased incremental R&D program that fed the results of flight testing back into the development process before engineers established the final configuration for production aircraft would have revealed the wing fatigue and other problems in time to remedy them before the manufacture of production articles.[1] This would have controlled cost growth and eliminated the need for the retrofit program and perhaps even for the later RB-57F effort. Higher levels of operationally available aircraft could also have been sustained after initial operational capability.

The RB-57F program seems to bear out these assertions. The Air Force avoided concurrency by making no contractual or schedule commitment to production. Instead, the developer received a contract for the development of only two prototypes for evaluation by the Air Force.

COMPONENT AND FLIGHT TESTING: RB-57D & F

The RB-57D component and flight testing program not only overlapped the production phase, but was unusually abbreviated. Many immature or untested components and subsystems were designated for the aircraft. Although flight testing revealed serious deficiencies, the brevity of the test period prevented the discovery of many other problems that emerged only after operational deployment. These problems were so serious that they led to several groundings of the aircraft and an

[1] Rand research on wholly new developments suggests that more rigorous testing can improve the operational capability of the final product.

ongoing retrofit program, all of which substantially decreased the operational availability of the aircraft.

In the case of the RB-57F, the Air Force instituted a robust flight test program twice as long (in calender terms) as that of its predecessor. After thorough flight testing, the two prototype RF-57Fs were deployed with a reconnaissance wing for several months of operational testing. Only after the completion of this extensive program of R&D and operational testing did the Air Force award a production contract. Undoubtedly this development approach was largely responsible for the much improved reliability, operational availability, and decreased wing fatigue problems experienced with the RB-57F compared with the D version.

SKEWED OBJECTIVES: F-4K/M

The British program for modifying the F-4 Phantom clearly exhibited unsatisfactory cost and performance outcomes. Airframe R&D costs for the Royal Navy F-4K version rose by over 36 percent. Total R&D expenditures for the joint RAF/Navy Phantom modification program surpassed original estimates for a joint new development program by over 50 percent. The F-4K/M failed to deliver 30 percent performance improvements over the J-79 powered Phantom, as originally expected. These unsatisfactory program outcomes may be explained at least in part by skewed objectives.

In the early 1960s, Rolls Royce began development of an advanced engine (the Spey R.Sp.5R) in hopes of having it designated for the Navy Sea Vixen follow-on, the P.1154. With the cancellation of the P.1154 and the decision to adopt the F-4, the British government insisted on

the re-engining of the Phantom with the Spey primarily to support Rolls Royce's quest to remain in the forefront of engine technology. Both the RAF and Royal Navy, however, preferred the quicker and cheaper option of procuring the standard U.S. J-79-powered Phantom. Industrial considerations overrode military requirements and cost-effectiveness factors as the primary motivation behind this major modification effort. By insisting on the Spey, the government had designated an engine that was only in the earliest stages of development and thus posed a considerable technological risk. The engine development program eventually cost well over twice as much as originally projected, becoming the single most important factor contributing to the cost overrun for the F-4K/M modification program (see Table 6).

Much of the airframe R&D cost growth on the Spey Phantom program resulted from an original underestimation of the magnitude of the airframe modification effort required to re-engine with the Spey. The Royal Navy F-4K airframe was intended to be identical to the U.S. Navy F-4J except for the Spey engines, a longer nose landing gear, and a folding radome and radar antenna. The Spey engine, however, is larger than the J-79. The F-4, unlike the F-14, was not designed for re-engining, so extensive additional modifications were called for. These included an enlargement of the engine compartment, a 20 percent increase in inlet and duct area, substantial modifications to the lower rear fuselage, and a reduction in tailplane anhedral. The re-engining necessitated extensive equipment modifications or changes, including the airbleed and turbine starter systems, cockpit instrumentation, hydraulic and electrical provisions in the engine compartment, and repositioning

Table 6

ESTIMATED R&D COSTS FOR THE BRITISH SPEY PHANTOM

(millions of 1978$)

Part	Initial Estimates (June 1964)	Revised Estimates (May 1965)
Spey Engine	68	153
Airframe [a] (Naval Phantom, F-4K)	88	120
Airframe [b] (RAF Phantom, F-4M)	--	75
Airbleed & Gas Turbine Starter	--	9
R&D Modifications Shared with US [c]	29	29
Contingency	2-31	65-122
Total Estimated Program Cost	187-216	451-508
Actual Program Cost (Mid 1968)	--	474

SOURCE: House of Commons, Public Accounts, Evidence, 1967-68, pp. 463 and 564.
[a] Includes 2 aircraft for flight testing, and production tooling.
[b] Includes 2 test aircraft.
[c] For development to F-4J standards.

of the Sparrow missile hard points. As a result, airframe modification costs escalated dramatically.

The Spey F-4 modification program proved to be a disappointment in terms of cost and performance objectives largely because military and cost-effectiveness requirements were not accorded highest priority.

INCREMENTALISM: F-5

The F-5 program was initially corporate-sponsored and aimed at acquiring allied nations as customers. Customers' differing requirements promoted incremental modification improvement. Through a building block process--which saw several models of the F-5 between the initial Military Assistance Program version of the F-5 procured by DoD and the F-5E--the contractor incorporated guns, a new radar fire control system, a maneuvering flap system, arresting hooks, and a more powerful engine. This incremental approach substantially lessened technological risk for each discrete modification. In the early 1970s these incremental modifications were consolidated into a new version, the F-5E, which also included other improvements. An uprated engine version increased thrust by 22 percent, yet required only modest changes in the airframe. Unlike the F-4K/M program, the new engine version had been chosen to optimize performance improvements while minimizing the need for airframe modifications. More advanced avionics were chosen on the basis of performance, low cost, simplicity, reliability, light weight, and small size. Largely as the result of the strategy of using proven components and incrementalism, the F-5E program progressed ahead of schedule and under cost. The F-5E production buildup rate surpassed the expectations of both the Air Force and the contractor.

Recently Northrop initiated a second major modification improvement program for the F-5, the F-5G. A new engine, the GE F404, will be incorporated, again requiring modest air frame modifications. By all

appearances, the program is progressing satisfactorily. Incremental modification improvement seems to have paid off handsomely for Northrop.

CENTRALIZED PROGRAM MANAGEMENT: F-4E

Another tenet of successful modification programs in the past has been a centralized directing agency with clear lines of authority. The RB-57D program suffered from conflicts and overlaps with the concurrent B-57B program. In the case of the F-4E Advanced Avionics Integration Program (AAIP) the effect of establishing clear lines of authority is especially striking.

The Air Force established the AAIP to coordinate the development and installation of ten major avionics and weapon subsystems into the F-4E phantom. The ten subsystems were being developed independently by separate management organizations within Air Force Systems Command for incorporation on the F-4E and other aircraft. By the early 1970s, it had become painfully obvious that the lack of coordination and communication among the various subsystem management officers would result in costly and disruptive problems involving redundancy, incompatibility, space, cost, schedule, and performance. The AAIP was formed to rectify this situation.

For an initial period, however, the AAIP failed to function effectively because of poorly defined lines of authority. AAIP funding originally was from the subsystem program offices, so disputes and confrontations often arose. Disagreements developed over the funding and procedure for testing the integrated avionics modifications, responsibility for correcting deficiencies, and accountability for resulting schedule and cost variations.

Once AAIP authority had been clearly established, with the F-4 SPO as Office of Primary Responsibility, most of these problems dissipated. Duplicative DT&E and integration tasks were reduced, and three major subsystem redundancies or incompatibilities were identified at an early stage. According to the project manager, once the lines of authority were established, the AAIP saved a year or more of development integration time and a considerable amount of money.

SUMMARY: MODIFICATIONS AND "CLASSICAL" R&D PITFALLS

A careful examination of these and other case studies such as the CH-47D (see Appendix) reveals that in many respects major modification programs are not unlike R&D programs for new starts. Since major modification programs generally involve substantial R&D efforts, they are not immune to the "classical" acquisition pitfalls encountered on R&D programs for new starts. Indeed, it appears that the primary factors contributing to the less satisfactory outcomes in the modification case studies were many of the same factors that have been identified as often leading to poor results in *ab initio* R&D efforts. This point may seem obvious, yet it has been ignored in much of the current discussion of modifications and of pursuing a P^3I strategy. For this reason alone, the admonition to avoid "classical" R&D pitfalls bears repeating and, indeed, special emphasis. Those pitfalls most clearly associated with less satisfactory modification program outcomes in the case studies and that should be avoided in any modification effort include:

- R&D and production concurrency
- Insufficient component and flight testing
- Subordination of cost-effectiveness considerations to industrial or other factors
- Accepting major technological R&D risk rather than adopting a strategy of incrementalism
- Unclear lines of authority and diffuse management structure.

IV. OBSERVATIONS

This Note investigated P^3I and other modification strategies that have gained some currency today as force modernization alternatives. To be worthwhile a P^3I strategy assumes some degree of preplanning during a system's design stage. We reviewed several modification programs to examine the usefulness of a P^3I approach, to test its assumptions, and to study its benefits and costs. We also hoped to gain some insight into the preferred manner of conducting modification programs in general. Our observations fall into two categories: (1) the ability of designers to preplan for future modifications, and (2) modification R&D approaches.

PREPLANNING FOR FUTURE IMPROVEMENTS

Generally it is unlikely that designers can anticipate the types of modifications their aircraft might undergo far enough into the future and well enough for them to take specific steps beyond present good design practices. A review of the design origins of some of the most robust and long-lived airframes suggests that designers could not have had the foresight to envision the changes in requirements and modifications their designs underwent in later years. However, an **important exception to this observation is that subsystem-specific preplanning is possible if the time horizon is short. If subsystems are** under development but not quite ready for incorporation into a new system, designers should be able to make provisions for incorporating such advances when they are fully tested and available. The F-14 is

perhaps the best example of this sort of narrow preplanning. Using proven subsystems initially until one has confidence in the more advanced subsystems reduces R&D risks and uncertainties, which is likely to improve the relationship between final outcomes and estimates of initial cost, schedule, and performance. Although preplanning may require more prescience than can be expected, in certain circumstances preplanning of the sort required for the more limited notion of subsystem specific improvements does appear possible and may have important advantages.

Preplanning seems advantageous when:

- The time horizon is short, perhaps two to four years ahead, and
- The subsystems to be incorporated into the baseline version of the system are already under development.

Choosing to preplan in this manner entails some risks, principally in that the planned-for improvements and updates may not be funded or may fail for some other reason. This leaves the Service to settle permanently for what was initially thought to be only a transitional system. The additional investment in time and money during the design stage to facilitate P^3I is thus wasted. The Navy, for instance, has been frustrated in its attempts to upgrade the F-14. The fear that future upgrades might be eminently cuttable in the future might be alleviated by various funding or procurement techniques such as multi-year funding.

MODIFICATION R&D APPROACHES

In reviewing previous modification efforts we noted that the cost, schedule, and performance outcomes of these programs often varied considerably from initial estimates. A close look at both successful and less successful modification program results suggests that these results can be partly explained by the R&D approach taken. Modification programs are apparently not immune to the traditional pitfalls encountered on new starts. Thus we recommend:

- Avoiding highly concurrent development and production.
- Allocating sufficient time and resources to test subsystems and the final integrated system.
- Minimizing technological risks by pursuing incremental advances.
- Providing a central management office to coordinate each major modification effort.

It seems unreasonable to expect designers to envision the kinds of modifications that might be made well into the future, and it would not be possible to make special provisions in the initial design to facilitate future unspecified modifications. Therefore we recommend that the Air Force adopt a P^3I strategy only for circumstances where subsystems are already in development but not mature enough to be incorporated in the initial version of the aircraft. In such cases more modest preplanning is necessary than that implied by most definitions of P^3I, which seem to demand a degree of long-range planning that cannot be supported by past experience. Further, modification programs both in

dollar terms and in their ability to enhance force effectiveness are important force modernization alternatives and often contain elements analogous to new R&D programs. Hence avoiding traditional new-start R&D pitfalls has relevance for major modification programs, whether or not they have been undertaken in a P^3I context.

Appendix

SELECTED CASE STUDIES

We selected a diverse group of major modification programs for detailed case studies to enlighten our analysis of P^3I and modification procedures in general. These programs span a period of several decades, include aircraft from all three services, and exemplify a wide range of modification strategies, objectives, and outcomes. A careful and detailed examination of these past programs has revealed several broad lessons on the conduct of modification programs and some insights into the usefulness of conducting a P^3I program. The following section is intended only to provide a brief outline and summary of the major programs examined.

A-7A AND A-7D

In May 1963 the Navy released RFPs to industry for an austere, inexpensive, single seat, light attack aircraft powered by the TF-30 engine. To minimize R&D costs, DoD argued for the modification of an existing aircraft equipped with off-the-shelf subsystems. Ten months later the Navy selected the Vought V-463 design, a modification of the Vought F-8 Crusader carrier-based fighter. Despite similarities in appearance, however, The A-7A (Vought V-463) shared with the F-8 only 13 percent by weight of its airframe structure and 7.6 percent of its tooling.

Subsequently the Air Force decided to adopt a modified version of the A-7A as a lower-cost solution to its close air support requirement. The Air Force suggested 42 changes for its version, the A-7D, including

improved avionics, improved gun, and the upgraded TF-30-P-8 with afterburner, for a total weight increase of 1,600 pounds.

During development a variety of factors led to increasing complexity and cost for the A-7D and decreasing commonality with the A-7A. Partly because of lessons learned in Viet Nam, the Air Force selected a more advanced avionics suite in August 1967 that included a digital computer with radar and HUD. Since the program's inception, the Air Force had also been dissatisfied with the thrust rating of the TF-30-P-8. The cost to develop a new engine was considered prohibitive, but a satisfactory afterburner for the TF-30 would considerably limit range because of increased weight and fuel consumption.

Because of the critical requirement for more thrust, the development of a new engine was nonetheless approved in April 1966. Yet the new engine could not possibly be ready in time for the scheduled delivery of the first A-7Ds. At this point the Air Force began to explore the possibility of licensed production of a modified Rolls Royce Spey-25 turbofan. The Spey was a lighter engine, already under development, and could easily be accommodated in the A-7D airframe. In addition, adoption of the Spey would help offset British purchase of the F-111 and licensed production of the F-4. By the end of 1966 the Spey, designated the TF-41, had been selected.

These changes in the program strained relations between LTV and DoD. The company believed that the Air Force had always been unenthusiastic about a modified Navy aircraft dedicated to close air support, and consequently resisted changes that might disrupt the program and render it more vulnerable to cancellation. LTV generally

opposed the avionics and engine changes as costly exercises that would increase technological risk and enhance the likelihood of schedule slippage. Once the Air Force decided to incorporate more sophisticated avionics, LTV fought successfully for overall management of avionics integration. Some friction emerged over measurement of accuracy, reliability guarantees, and correction of latent defects. The firm was even less enthusiastic about the adoption of the Spey engine, arguing that the untested engine substantially increased R&D risk. Eventually these concerns proved justified. The A-7D program proved less than totally successful as development costs escalated and serious engine problems emerged after operational deployment.

THE CH-47D

The evolution of the CH-47 medium lift helicopter aptly illustrates an incremental product improvement modification approach. As originally conceived in the mid-1950s the basic design was guided by a philosophy of simplicity, flexibility, and provision for future growth. The A, B, and C versions delivered to the Army during the decade after 1962 incorporated important incremental improvements. By 1970, however, the Army had developed new requirements and, because of the growing age of the CH-47 fleet, was clearly faced with a major helicopter modernization decision. The overriding need was for improvements in RAM,[1] vulnerability, survivability, and flight safety. To achieve these improvements the Army considered an on-condition maintenance overhaul

[1] Reliability and maintainability.

program, improving the existing fleet, or the initiation of a new development program.

The Army and Defense Department eventually decided on a modification strategy to minimize cost and technological risk. The program emphasized primarily the improvement of reliability and maintainability and the reduction of operating and support costs. Eight subsystems were designated for improvement: rotor blades, drive system, hydraulic system, electrical system, advanced flight control system, cargo suspension system, TSS-L-11 RAM-D engines, and auxiliary power unit. The program specified ambitious goals for the reduction of maintenance failure rates, direct operating costs, major accident rate, and maintenance manhour requirements, and for increases in mission reliability and fleet lift capability.

The helicopter modernization program envisioned the modification of 361 CH-47 aircraft (104 As, 74 Bs, and 183 Cs) to the improved D configuration, plus the acquisitions of about 190 new CH-47Ds. Army estimates in September 1977 put development and modernization costs at $1.6 billion and new procurement costs at about $1.2 billion in FY 1975 escalated dollars. Because of the expected high cost and large scale of the overall modernization program, Malcolm Currie, DDR&E, recommended in 1974 that the program receive DSARC review and approval. ASARC/DSARC II evaluation required a special Army study group to prepare extensive documentation demonstrating that modification of the CH-47 was the most cost-effective means of meeting the medium lift helicopter modernization requirement. The successful completion of these studies led to the award of an engineering development contract to Boeing Vertol in 1975. In June of the following year the same firm received a $102 million

development contract to design, fabricate, and demonstrate seven of the subsystems in three prototypes with developmental testing scheduled to commence in 1980. The modification effort will include a substantial remanufacture of the airframe with disassembly and structural reinforcement of major portions of the fuselage. The Army elected, however, to conduct a separate $8.5 million engine and rotor blade improvement program as an independent modification of the CH-47C.

Although the CH-47D program is still in its early stages, it received extensive criticism from the GAO in 1978. Despite the series of studies conducted early in the decade, the GAO alleged that the Army had not seriously considered options other than modification of the CH-47. Army officials insist that both alternative aircraft and new development were closely examined. For example, the Army evaluated the Sikorsky CH-53E Super Stallion but concluded the aircraft's capabilities and cost were both excessive. In addition, the Army estimated that a new development program would have cost from three to five times more in R&D funds than modification of the CH-47 without providing a commensurate improvement in capabilities.

THE F-4K/M

In the early 1960s the British Ministry of Defense supported the development of the Hawker-Siddeley P.1154 as a replacement for RAF Hunters and Royal Navy Sea Vixens. It soon became evident, however, that the requirements of the two services could not be reconciled in the same aircraft. In February 1964 the MoD canceled the naval version of the P.1154 in favor of acquisition of McDonnell F-4 Phantoms equipped

with Rolls Royce Spey engines. One year later the RAF P.1154 program was also terminated. Subsequently, the government established a joint RAF/Royal Navy Spey Phantom program to provide aircraft for both services.

Although it was thought that the Spey would augment F-4 performance, the RAF preferred the cheaper and quicker option of procuring standard U.S. J-79 Phantoms. By this time, the Royal Navy had also adopted this position because of expected improvements in the J-79 and carrier launch techniques. Nonetheless, the government insisted on the Spey re-engining. As the Assistant Secretary, Ministry of Technology, testified in Parliament, "The decision to use the (Spey) engine in the RAF version was mainly taken on industrial grounds."[2]

In May 1965 the government calculated new R&D cost estimates for the joint program. R&D costs had risen substantially because of cost growth on the Spey R&D program and because of a better appreciation of the magnitude of airframe modification costs required for re-engining and for installation of British avionics and other components.

The escalation in estimated costs to modify the Phantom took place between February 1964 and May 1965 and became the object of considerable controversy in Britain. Cost growth on the Spey R&D program was a major contributing factor. However, experts also grossly underestimated the cost of airframe modifications to accommodate the Spey and other British components. Engine development estimates escalated by 125 percent; airframe modification estimates increased by at least 36 percent. In the final estimate airframe modification costs (including test aircraft

[2] Public Accounts, 1967-68, p. 472.

and production tooling) totaled over 27 percent more than the escalated engine development costs, excluding other airframe modifications shared with the United States.

The Royal Navy F-4K airframe was intended to be identical to the U.S. Navy F-4J except for the Spey engines, a longer nose landing gear, and a folding radome and radar antenna. But since the Spey is larger than the J-79, extensive additional modifications were called for. These included an enlargement of the engine compartment, a 20 percent increase in inlet and duct area, substantial modifications to the lower rear fuselage, and a reduction in tailplane anhedral. The re-engining necessitated extensive equipment modifications, such as the airbleed and turbine starter systems, cockpit instrumentation, hydraulic and electrical provisions in the engine compartment, and repositioning of the Sparrow missile hard points. Some airframe modifications may have been undertaken to accommodate British equipment.

The Spey Phantom does not deliver the 30 percent performance improvement in all areas originally hoped for. This point is of only secondary importance, because by 1965 the British were insisting on re-engining the F-4 primarily for domestic industrial reasons and not for performance improvements.

Re-engining the Phantom proved to be a generally unhappy experience for the British. It showed that installing a slightly larger engine in the Phantom necessitated substantial airframe modifications; the actual cost of the airframe modifications far exceeded original expectations; and that major modification of an aircraft for reason other than cost and military effectiveness can be nearly as expensive as developing an entirely new aircraft.

F-4E AVIONICS

In the late 1960s and early 1970s the following ten major avionics and weapons subsystems were being developed independently for incorporation as Class V (performance improvement) modifications on the McDonnell-Douglas F-4E Phantom: the AN/ARN-101 Tactical LORAN, PAVE TACK, GBU-15 Glide Bomb, Advanced Maverick, the Digital Scan Converter, PAVE SPIKE, PAVE PENNY, Video Tape Recorder, Wild Weasel, and Line Replaceable Unit-1. Inadequate coordination and communication existed among the separate management organizations within Air Force Systems Command responsible for the development of each subsystem. Different contractors were developing each subsystem according to their own schedule. Many of the subsystems required rewiring of the aircraft's electrical system. All needed additional cooling and power provisions, and control panel display and switching space. Separate, redundant, and occasionally incompatible control panel displays and switching were being developed for each subsystem. No attempt was made to integrate or coordinate the installation of the various subsystems. As a result, by 1973 the increasing likelihood of costly and disruptive interface problems began to be recognized.

Late in 1973 the Air Force established the Advanced Avionics Integration Program (AAIP) to insure various subsystems being developed under separate management directives would be effectively integrated with one another and the baseline aircraft. AFSC designated the F-4 SPO as the Office of Primary Responsibility for the management of the AAIP,

and established the Interface Control Working Group, Joint Management Team, and Advanced Cockpit Committee to resolve subsystem integration problems of redundancy, incompatibility, space, cost, schedule, and performance.

The AAIP proved its worth in several respects. It opened regular lines of communications among the F-4 SPO, the subsystem program offices, McDonnell-Douglas, and the subcontractors. Centralized planning reduced duplicative DT&E and integration tasks. The program identified and remedied at least three major hardware deficiencies: the duplication of cockpit switches and panels, the inadequacy of the Laser Code Control Panel for Pave Spike, and the incompatibility of the TISEO Radar Logic Unit with Pave Tack Video. These deficiencies may not have been detected until much later in the modification program without the AAIP. According to an AAIP project manager, the modification program might have slipped a year or more and cost considerably more without the centralized coordination effort.

Despite its successes, the AAIP could have been conducted in a more efficacious manner. Initially considerable confusion resulted from a failure to clearly delineate the areas of responsibility of the F-4 SPO in relationship to the subsystem program offices. The definition of the baseline modification program remained in doubt for some time; eventually four subsystems (Pave Spike, Pave Penny, Wild Weasel, and the LRU-1) were deleted. Funding proved to be inadequate and highly incremental. Initially AAIP funding was drawn from subsystem program offices resulting in time-consuming disputes and confrontations.

The AAIP stressed flight testing of the integrated avionics modifications, but this was hampered by a shortage of funds or disputes over lines of authority. Available test units and the full cooperation of subsystem program offices were not always forthcoming. The subsystem program offices expressed concern over the responsibility for and funding of corrections of subsystem deficiencies, and over accountability for schedule slippage in the Class V Modification schedule. Testing revealed major difficulties in isolating the specific subsystem responsible for inadequacies in the operation of the integrated weapon system.

The F-4E AAIP clearly demonstrated the advantages of coordinating the management of several avionics subsystem programs into one large centrally directed modification program. The AAIP would have functioned more smoothly if its authority had been more clearly defined and funding had been more adequate and timely.

THE F-5 SERIES OF MODIFICATIONS

After a management change in 1953 Northrop began exploring lightweight fighter designs that emphasized simplicity, ease of maintenance, and decreased procurement, operating, and support costs. One of the first results of this effort was N-102 Fang lightweight day fighter design proposed to the Air Force in 1953. In one of the earliest attempts to anticipate modifications, Northrop engineers designed the Fang to facilitate future engine growth. The airframe could be re-engined in the field to accommodate four different engines then in various stages of development, thus improving performance while

avoiding major modifications to the airframe. The Air Force rejected the design, however, arguing that the airframe would not be optimized for the performance capabilities of any given engine and could not possibly anticipate future technological trends.

With the experience gained from the Fang design, Northrop went on to develop a new lightweight, high-performance, low cost day fighter design designated the N-156. In 1956 the Air Force adopted a version of the N-156 as a new trainer, the T-38. Northrop continued on a private venture basis to develop the fighter version. Air Force requirements for increasingly complex multirole, high-speed, high-altitude fighters led Northrop to turn to allied governments as potential customers more interested in a lightweight austere fighter with growth potential. By 1959 DoD had agreed to support the further development of the fighter with total funding of $23 million as a Military Assistance Program (MAP) aircraft.

Discussions with potential users contributed during advanced development to Northrop's stress on multimission flexibility, austere airfield capabilities, low cost, minimal support requirements, and growth possibilities. For example, engineers designed the nose to enclose some 40 cubic feet to accommodate many variations of fire control equipment, armament radar, and reconnaissance layouts.

Hardware development and flight testing of the F-5A, as the N-156 was now called, proceeded smoothly between 1959 and 1962. The first MAP customer, Iran, prompted the installation of guns in the nose forward of the engine inlet. Differing needs of various other customers encouraged a policy of incremental improvement and vindicated Northrop's philosophy

of design for growth. Canadian and Norwegian F-5s incorporated fire control computers and more advanced gunsights. Spain's requirements necessitated the installation of a new radar for the fire control system. Dutch models featured a maneuvering flap system, Norwegian aircraft possessed arresting hooks, and Canadian F-5s boasted a more powerful J-85-15 engine.

By the early 1970s most of these incremental changes had been consolidated and further improved to produce the F-5E. A new version of the J85 engine increased thrust by 22 percent but required only minor modifications of the fuselage. A more sophisticated radar and other avionics vastly improved air-to-air capabilities. Later Swiss and Saudi requirements led to further avionics upgrading. Production build-up rates and actual costs proved to be far more favorable than either the Air Force's or Northrop's initial estimate for this second generation MAP fighter.

In 1974, Northrop began developing the F-5G, a third generation improved version of the original F-5A Freedom Fighter. This aircraft will incorporate the 16,000 lb thrust GE F404 engine, a new wing design, advanced avionics, fly-by-wire control system, and other improvements. To accommodate the new engine, inlets have been enlarged and extended several inches forward. The inlets have been designed to facilitate further enlargement for additional growth versions of the F404. The very modest empty weight increase combined with a tripling of thrust will significantly augment performance of a basic airframe designed a quarter of a century earlier with future modification upgrading in mind.

THE F-14

Like the N-102 Fang, the Grumman F-14 Tomcat airframe was originally designed to facilitate installation of higher thrust engines and enhanced avionics. The basic design concept provided for this contingency by allowing for higher air flow and the larger size of a new engine.

With growing skepticism over the capability of the F-111B to perform the fleet air superiority mission adequately, the Navy initiated the Navy Fighter Study (NFS) in 1967. The VFX concept for a lighter, faster, more maneuverable air superiority fighter emerged from the NFS in 1968. Moderate development costs and risks were central considerations in formulating the VFX concept. Consequently the NFS recommended that the VFX combine an advanced airframe with the TF-30 engine and AWG-9 Phoenix missile system, which were already being developed and tested for the F-111B. Since the VFX would use state-of-the-art components, the NFS placed great emphasis on growth potential in the new design so that when they became available advanced technology engines and avionics could be incorporated with little or no airframe modification. The Navy issued RFPs to five firms in mid-1968 and awarded the development contract to Grumman in February 1969. An important criterion determining the choice had been the growth potential exhibited by the Grumman design.

OSD originally authorized a total procurement of 722 aircraft. Only the first 67 would be F-14As; the rest (F-14Bs) would have the new high technology engine (F-401) being developed as the navalized version of the Air Force F-15 F-100 engine. Eventually the F-14C would be introduced with an improved fire control system and enhanced R&M.

In 1971 Deputy Secretary of Defense Packard slashed the total F-14 procurement to 313 and indefinitely postponed procurement of the F-14B because of mounting cost overruns, schedule slippage, and technical problems on the airframe, the TF-30 engine, and the advanced technology F-401 engine. Packard testified that installation of the F-401 would require only minimal airframe modifications; the decision to postpone procurement of the F-14B was determined by overall cost considerations and the status of the F-401 development program. Since 1971 the Navy has failed several times to win approval for the procurement of the F-14 with a higher thrust engine. However, the Navy and Grumman did re-engine two F-14As with developmental versions of the F-401. These prototype F-14Bs underwent a generally successful flight test program in the mid 1970s.

THE N-102 PROPOSAL

In the early 1950s the Northrop Corporation proposed developing a day fighter, the N-102, which could accommodate four different engines, all then in various stages of development. Essentially this amounted to an ambitious subsystem-specific P^3I design. The aircraft would be delivered with the J65 engine and later incorporate an improved version of the J65, and still later the J57 would be installed. Finally, the fighter would be re-engined with the X24A. According to Northrop's calculations substantial savings would accrue to the Air Force by taking this tack rather than developing a new airframe for each engine. The Air Force agreed that this approach seemed to have substantial cost savings but rejected the program for other reasons.

The Air Force had two principal concerns about the project. First the Air Force felt that the overall performance of the N-102 would be poor, both initially and further in the future, because the system's airframe would not have been optimized for a particular engine.[3] Second, reflecting on the pace of advances in air vehicle technology in the previous decade (1943-1953) the Air Force doubted anyone could adequately anticipate the direction of future technology. Thus the N-102 never got beyond the mock-up stage.

THE RB-57D

Late in 1952, engineers at Wright Field became interested in developing a very high altitude reconnaissance aircraft with a ceiling over 60,000 ft and a combat range of 1800 miles at subsonic speeds. In mid 1953, six-month study contracts were awarded to Bell, Fairchild, and Glen L. Martin. The first two companies proposed entirely new designs, while Martin suggested modifying the B-57B medium attack bomber with much larger wings, new engines, and new avionics. The Bell X-16 was judged the best design and the Air Force approved development. By this time, however, SAC Headquarters had generated an urgent requirement for a high altitude reconnaissance aircraft. Consequently a dual program was initiated; officials approved the RB-57D proposal as the quickest and cheapest interim solution. Somewhat later the Air Force also

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[3] Ironically, few aircraft of that period ever were deployed with the engines initially intended for them. See L. L. Johnson, The Century Series Fighters: A Study in Research and Development, The Rand Corporation, RM-2549-PR, May 20, 1960.

authorized the development of the Fairchild X-17, an even higher performance aircraft with a similar mission.

The RB-57D made its maiden flight late in 1955, about three months behind schedule. Flight testing soon disclosed serious design deficiencies related to the rapid appearance of serious wing fatigue problems. Attempts to hasten operational availability through further compression of the already minimal flight test program exacerbated the situation.

Officials had conducted the B-57 modification program from the beginning in an atmosphere of extreme urgency. In an effort to achieve operational availability as quickly as possible, all aspects of the program were conducted simultaneously. Martin received a contract for both R&D and production. Production engineering and preparations commenced at the very beginning of development. The Air Force unwisely designated immature or insufficiently tested subsystems such as the J-57-P-9 engine and certain mission avionics for the aircraft. Martin began construction of the first production aircraft only weeks after the first flight of the first test aircraft. More than half the production run had been completed by the time flight testing revealed the seriousness of the wing fatigue problem. Indeed, flight testing was still underway when the last production RB-57D was completed. At least 12 of the 20 production aircraft had to undergo an extensive retrofit program for strengthening the wing during operational testing. These problems contributed to considerable schedule slippage and cost growth. However, the extreme urgency of the program had led to the contractual definition of an unusually short and probably unrealistic RDT&E schedule.

Despite the many difficulties encountered, the RB-57D program must be characterized as at least modestly successful, particularly when contrasted with the parallel X-16 and X-17 programs. The Air Force canceled both of these programs in 1955 because of rapidly escalating cost estimates, schedule slippage, and mounting evidence that the aircraft would not be capable of substantially outperforming the much cheaper RB-57D.

The RB-57D generally performed according to expectations, but since the X-16 and X-17 programs had been eliminated and the U-2 proved deficient in payload for certain missions, it remained in the inventory much longer than originally expected. Consequently, its wing fatigue problems, maneuverability limitations, and engine flameout tendencies proved increasingly onerous.

Although SAC began receiving operational aircraft only 21 months after the initiation of the crash development program, the operational readiness of the aircraft remained low, because of the need to repair and reinforce wings and integral fuel tanks of the RB-57D. By the early 1960s the aircraft's wings were literally falling off. The Air Force recognized that to maintain its manned high altitude reconnaissance capability it would have to initiate a new development program or another major modification effort designed to avoid the pitfalls encountered on the RB-57D program.

THE RB-57F

The Air Force inaugurated a second program in the early 1960s to substantially modify B-57 tactical bombers to fulfill the need for a very high altitude reconnaissance aircraft. Severe wing fatigue problems necessitated the procurement of a replacement for the aging fleet of RB-57Ds. In addition it was hoped that an improved modification of the B-57 would eliminate the problems of engine flameout, poor high altitude maneuverability, and unsatisfactory service ceiling that degraded mission capability in the D version.

Engineers at General Dynamics had privately developed a design for an improved version while working on a contract to repair wing fatigue damage on RB-57Ds. In March 1962 the Air Force awarded General Dynamics a six month study contract for configuration modernization of the B-57 for high altitude flight with a payload in excess of two tons. After satisfactory completion of the study, GD received a contract for the construction of two prototype RB-57Fs. The Air Force avoided concurrency by making no formal commitment to production and by establishing a robust flight test program.

With an entirely redesigned and much larger wing, TF-33 turbofans, optional J-60-P-9 engines,[4] and new avionics, the F differed substantially from the D version. Fuselage and empennage changed little from the standard B-57. Bonding technology developed for B-58 Hustler production was applied to the honeycomb wing panel construction.

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[4] Small auxiliary turbojets for increased altitude and payload performance.

Granted an unusually high priority similar to that for the original D program, the F program bypassed normal procedure and red tape. GD completed the first prototype only 8 1/2 months after initial contract signing. During this period industry had conducted a full series of wind tunnel tests and had developed a new crew ejection seat system and a very high altitude, high resolution camera.

In June 1963 GD and the Air Force began a six month flight test program with the two prototypes. At the end of the year an Air Force clandestine reconnaissance wing (7407th Combat Support Wing) based in Germany began using the aircraft, which officially became operational in February 1964. Only some months later did the Air Force award GD a production contract for an additional 19 RB-57Fs. Eventually the firm modified and rebuilt 14 B-57Bs, three As, and four Ds to fulfill its contract with the Air Force.

The RB-57F surpassed its predecessor in top ceiling, payload, and high altitude maneuverability. The program encountered no serious schedule slippage or cost growth. By the late 1960s, however, wing fatigue again became a serious problem. When faced in 1973 with the prospect of initiating an extensive wing modification program to rectify this problem, the Air Force chose instead to deactivate the last remaining flying RB-57Fs. Nonetheless, the F versions had satisfactorily performed their mission for years with far fewer wing fatigue problems than experienced with the D.

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